Dual-Band Frequency Reconfigurable Microstrip Patch Antenna on Wearable Substrate for Wi-Fi and Wi-MAX Applications

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Abstract-In this paper the design of wearable dual band frequency reconfigurable microstrip patch antenna is presented for wireless communication services (i.e. Wi-Fi at 2.44 GHz and WiMAX at 3.54 GHz). For body-worn and wearable applications, the antenna is employing 1 mm thick Denim Jeans textile material as a substrate with dielectric constant of 1.7 and loss tangent of 0.0001. The proposed microstrip patch antenna with volume of $105.38 \times 90 \times 1$ mm^3 has been reconfigured using optical switches to operate at two different frequencies depending upon the switching mode. The antenna operates at single band mode at 2.44 and 3.54 GHz frequency bands, when the switches the switches are ON and OFF, respectively. The proposed structure has an operational bandwidth of 2% (50 MHz) and 1.13% (40 MHz) at the resonant frequencies of 2.44 and 3.54 GHz, respectively. Better impedance matching characteristics with input impedance in acceptable range of 51-52.5 Ω and VSWR nearly equal to 1.05 has been provided by the proposed antenna. Directional gains of 5.73 and 9.17 dB are achieved at 2.44 and 3.54 GHz frequencies, respectively with maximum efficiency of 94.6%. Proposed wearable frequency reconfigurable dual band microstrip patch antenna has the capability to be used in wearable, medical, safety, rescue, body-worn, security and military applications. The proposed microstrip antenna is designed, simulated and analysed in Computer Simulating Technology Microwave Studio employing Finite Integration Method.

Keywords-Dual-band, Wearable, WiFi, WiMAX, Microstrip, Jeans, Patch, Low Profile, Reconfigurable.

I. INTRODUCTION

Modern wireless communication technology provides flexibility to the users of electronic portable devices. The innovation in technology have gained a peak value in demand graph that humans should be able to wear electronic devices for communication purposes in body area networks, personal area networks and other fixed/mobile networks. For effective communication between different wearable devices in wireless communication networks, a wearable component made from textile materials known as wearable antenna is required. Wearable antennas employed on textile materials have the capability to radiate electromagnetic waves of specific wavelengths. For this reason, these antennas are used in various applications including medical, sports and military [i].

Wearable and body-worn antennas, made up from textile materials [ii-iii], can be worn directly as button antennas [iv] or can be integrated into clothing [v]. In literature, the authors have discussed wearable whip antenna for the first use in military applications [vi]. Similarly, Telemedicine devices are observed utilizing the wearable antenna technology for medical applications [vii-viii]. In [ix-x], it is reported that the wearable antennas are introduced as flexible metallic strips on textile materials as substrates. The authors have presented the design of wearable dual band antenna in [xi]. However, the above described antennas are radiating electromagnetic waves at different frequency bands irrespective of the user need. To consider particular communication services required by the user, the best solution is to use frequency reconfigurable antennas.

Reconfigurable antennas have the capability to reconfigure its characteristics such as resonant frequency, far-field radiation pattern and electric field polarization, depending upon the integrated mechanisms. The resonance of frequency reconfigurable monopole, dipole, loop, microstrip patch and slot is controlled by the effective length of the radiating structures in these antennas. In frequency reconfigurable antennas, the resonant frequency is switched from one band to another band by incorporating electronic switches within the antenna including PIN diodes, RF MEMS and optics. In [xii], the authors have designed dual-band frequency-reconfigurable textile antenna for wearable applications using PIN diode switching. In [xiii], the antenna is reconfigured using RF MEM switches. The authors have discussed the design of dual band frequency reconfigurable microstrip antenna using varactor diode switching in [xiv].

In this paper, a wearable frequency reconfigurable dual band microstrip patch antenna is designed on a 1mm thicker textile material, the Denim Jeans. The proposed wearable antenna is configured to transmit and receive electromagnetic waves at Wi-Fi and WiMAX frequency bands by using optical switches. The commutation of optical switches for simulation purposes has been realized in such a way that the resistance is kept as low as 5 Ω and as high as 1 GΩ for switch ON- and OFF-state, respectively. Rest of the research efforts are organized and arranged section-wise in the following manner: In section II, the geometrical structure and design methodology of wearable Dual band frequency reconfigurable microstrip patch antenna is discussed. Section III presents the performance, simulation results of the antenna. Finally, the article is concluded in Section IV.

II. Geometry and Design Methodology

The dimensions of proposed wearable microstrip patch antenna for Wi-Fi (2.44 GHz) and WiMAX (3.54 GHz) applications are shown in Fig. 1. Normally, -10dB band-width of microstrip patch antenna is narrow because of the fact that it provides a single resonant frequency for operation. Thus, to lead in multiband performance characteristics it is required to design a reconfigurable microstrip radiating structure that has the ability to radiate electromagnetic waves at two or more than two frequencies. For this reason, this design structure is adopted to achieve reconfigurability and dual-band frequency mode in the antenna, with good input impedance matching characteristics in the respective operating frequency

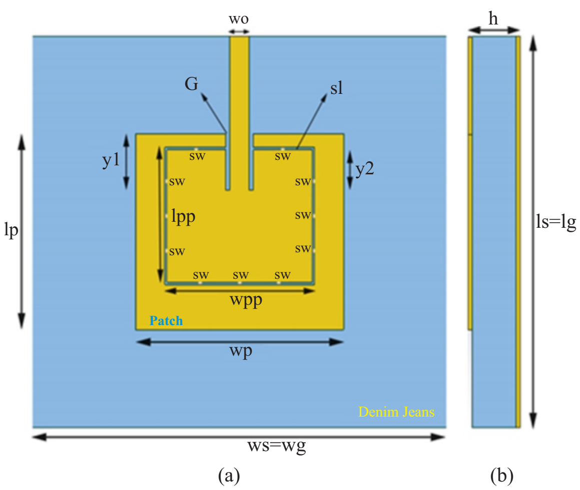


Fig. 1. Structural Dimensions of Wearable Microstrip Patch Antenna, (a) Top View (b) Right Side View

In this design, the basis of the radiator is a microstrip rectangular patch with the dimensional lengths and widths (i.e. lp×wp, for lower resonance; and lpp×wpp, for higher resonant frequency). To make the antenna capable for body-worn and wearable applications, the patch is employed on 1 mm thick textile material, Denim Jeans as a substrate with dielectric constant of 1.7 and loss tangent of 0.0001 [xv]. The proposed wearable antenna is fed via 50Ω microstrip line with width of wo= 5mm. The microstrip line feeding method is easy to fabricate, simple to model and input impedance is matched efficiently by adjusting the inset position of the line [xvi].

To achieve reconfigurability, the two rectangular patches are separated by a rectangular slot of 0.5mm for the integration of eleven switches, as depicted in Fig. 1. The spacing between the patches is adjusted in such a way that the outer patch resonates at lower frequency band (i.e. Wi-Fi @2.44 GHz) whereas the inner patch provides resonance at higher frequency band (i.e. WiMAX @3.54 GHz). The effective lengths and widths of wearable microstrip patch are calculated using well-known transmission-line model theory in [xvii]. Resonant lengths of the two concentric patches in terms of guided wavelengths (i.e. $\lambda_{2.44}$ and $\lambda_{3.54}$) are calculated using the equations given as:

$$L_{2.44} = lp = \frac{\lambda_{2.44}}{2} - 2\Delta L_{2.44} \tag{1}$$

$$L_{3.54} = lpp = \frac{\lambda_{3.54}}{2} - 2\Delta L_{3.54} \tag{2}$$

Where λ_{fr} is a guided wavelength which can be found for a particular frequency f_r in a following equation as:

$$\lambda_{fr} = \frac{c}{f_r \sqrt{\varepsilon e}} \tag{3}$$

In the above equation, c represents the velocity of light and the parameter ε_e is known as effective dielectric constant, given in the equation as:

$$\varepsilon_e = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1 + 12\frac{h}{W_{fr}}\right]^{-1/2} \tag{4}$$

Where W_{fr} is the width of rectangular patch at frequency f_r, h is the thickness of substrate material used (i. e. Denim Jeans in this case) and ε_r is known as effective relative permittivity. The widths of both the inner and outer patches at their respective frequencies are calculated using the equations written as:

$$W_{2.44} = wp = \frac{\lambda_{2.44}}{2}\sqrt{\frac{2}{\varepsilon r+1}} \tag{5}$$

$$W_{3.54} = wpp = \frac{\lambda_{3.54}}{2}\sqrt{\frac{2}{\varepsilon r+1}} \tag{6}$$

The extension in length of the patches ΔL_{fr} mentioned in above two equations (i.e. eq-1 and -2) is found as:

$$\Delta L_{fr} = 0.412h\frac{(\varepsilon_e + 0.3)(\frac{W_{fr}}{h} + 0.264)}{(\varepsilon_e - 0.258)(\frac{W_{fr}}{h} + 0.8)} \tag{7}$$

The lengths, widths and feed-line depths calculated using above mentioned equations are adjusted in simulation for the desired frequencies at 2.44 and 3.54 GHz. The proposed wearable microstrip antenna has an over-all dimensional volume of $105.38 \times 90 \times 1 mm^3$. Table I summarizes the dimensions of proposed wearable reconfigurable microstrip patch antenna.

TABLE I
SUMMARY OF DIMENSIONS OF WEARABLE MICROSTRIP

Symbol	Quantity	Values (in terms of guided wavelength, λ=94.3 mm)
ls =lg	Length of substrate	0.95 λ
Ws=wg	Width of substrate	1.12 λ
lp	Length of patch	0.5 λ
wg	Width of ground	0.56 λ
Lpp	Length of inside patch	0.33 λ
y1	Outer patch difference	0.14 λ
wpp	Width of inside patch	0.4 λ
y2	Inner patch difference	0.1 λ
G	Gap	0.011 λ
SI	Slot length	0.005 λ
Wo	Width of feed line	0.053 λ
h	Height	0.011 λ

III. SIMULATION AND RESULTS

The proposed wearable microstrip patch antenna, employing denim jeans as a substrate, is designed, simulated and analysed using Computer Simulation Technology Microwave Studio (CST MWS. In this software environment, denim jeans substrate was defined by adding new material with permittivity of 1.7 and loss tangent of 0.0001. The radiating element and ground plane uses copper metal as a conducting material. To analyze the results of the antenna, open-add-space boundary conditions and the transient solver was used in simulation. The frequency range was set in the range from 2 to 4 GHz, as the antenna is designed for 2.44 and 3.54 GHz bands. Excitation of the patch antenna is accomplished by assigning a wave-guide port to the face of 50Ω microstrip transmission feed-line. The antenna parameters such as Magnetic- and Electric-field Gain, -10dB Return Loss, Scattering parameter, Surface E-fields and Voltage Standing Waves Ratio (VSWR), 3D Far-field radiation patterns are evaluated and investigated for performance analysis and are presented below in this section.

Switches in the radiating element of the patch are inserted in the positions represented as *sw*. When all the switches are ON, the antenna operates at 2.44 GHz. Similarly, the patch antenna achieves resonance at 3.54 GHz when all the switches are OFF. Table II explains the switching mechanism and resonant frequency modes.

TABLE II
SWITCHING MECHANISM OF WEARABLE AND RECONFIGURABLE MICROSTRIP PATCH ANTENNA

S. No	Switch Condition	Frequency
1	ON	2.44 GHz
2	OFF	3.54 GHz

Microstrip patch antenna gives -10 dB reflection coefficient (S_{11}) of -29.49 dB at 2.44 GHz and -32.2 dB at 3.54 GHz, when all the switches are ON and OFF, respectively. The bandwidths in the respective lower and high frequency bands are 2% (50 MHz) and 1.13% (40 MHz). The plot of frequency versus S_{11} of patch antenna is given in Fig. 2. It can be observed from the graph that the antenna provides minimum reflections at 2.44 and 3.54 GHz frequencies. Additionally, the patch gives resonance at 3.376 GHz with S_{11} of -20 dB. However, at this additional band the antenna is not matched.

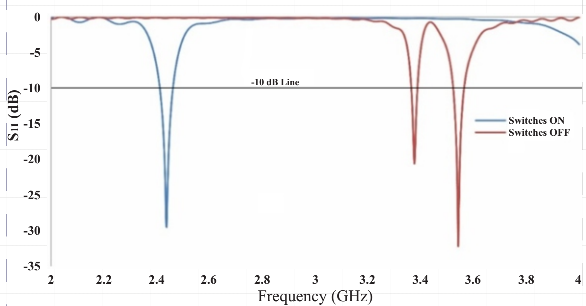


Fig. 2. Reflection coefficient (S_{11}) of Wearable and Reconfigurable Microstrip Patch Antenna in both switching modes

In Fig. 3, VSWR values of the antenna are plotted against frequencies, which clearly illustrate the fact that the antenna is satisfactorily matched with VSWR values of 1.069 at 2.44 GHz and 1.05 at 3.54 GHz frequency bands. Input impedance realized by the antenna structure is 51.5 ohms at 2.44 GHz and 52.46 ohms at 3.54 Ghz.

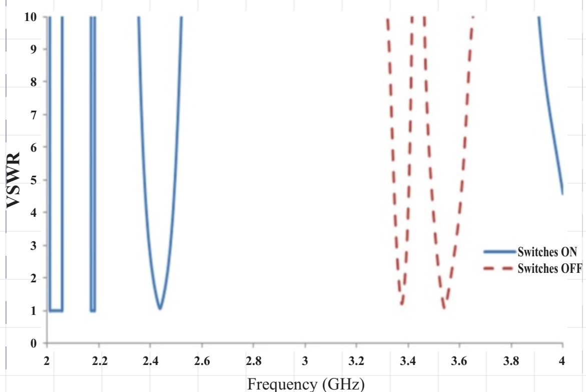
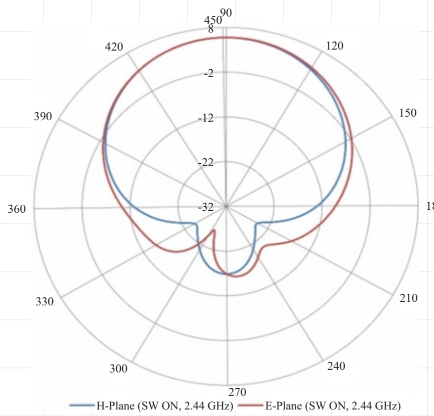


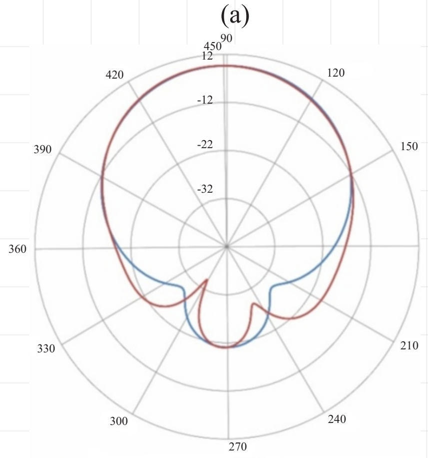
Fig. 3. VSWR values of Wearable and Reconfigurable Microstrip Patch Antenna in both Switching Modes.

E/H-plane gain patterns in both switching modes are depicted in Fig. 4 a and b. Gain of the antenna in ON-switch state is 5.728dB at 2.44 GHz. When all the switches are OFF, gain value of 9.167dB is achieved by the patch at 3.54 Ghz.

In Fig. 5 a and b, the surface electric fields can be observed at 2.44 and 3.54 GHz. From these figures, it has been observed that the inner patch is responsible for radiations at 3.54 GHz, whereas the outer patch radiates electromagnetic waves at 2.44 GHz. In other words the density of E-field is maximum at the edges of the outer patch which helps in generating the lower frequency band (2.44 GHz). This E-field density is maximum at the edges of the inner patch which contribute in generating the upper frequency band (3.54 GHz). The E-field density is minimum at the center of the patch. The proposed wearable antenna attains the maximum efficiency values of 51% (lower due to insertion losses) at 2.44 GHz and 94.6% at 3.54 GHz frequencies. Table III summarizes performance of the proposed wearable dual band patch antenna. The antenna gives sufficient gain (> 5 dB), directivity (>8 dBi) and bandwidth (1-2%) in both frequency bands.

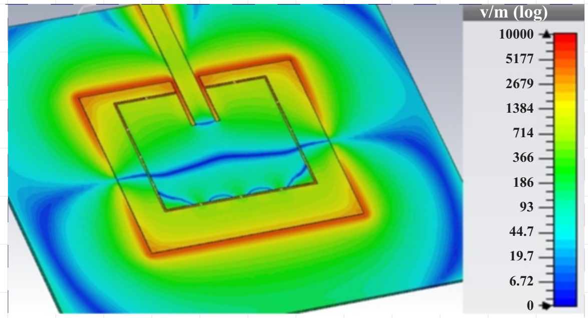


(a)

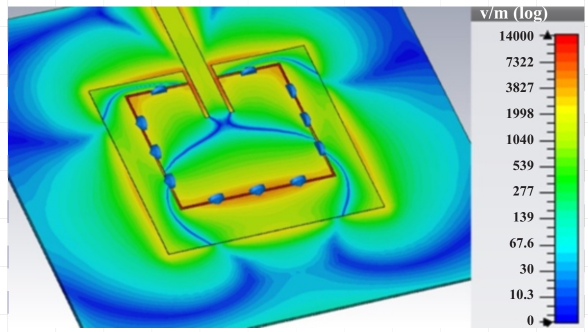


(b)

Fig. 4. Gain Pattern of Wearable and Reconfigurable Patch Antenna at (a) 2.44 GHz (All SWs ON) (b) 3.54 GHz (All SWs OFF)



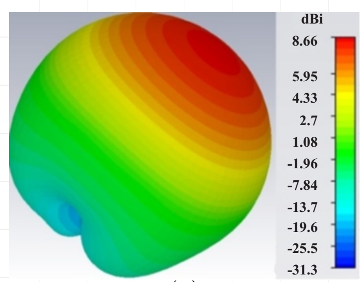
(a)



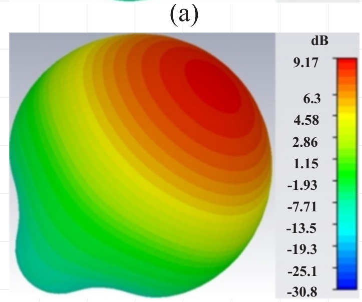
(b)

Fig. 5. Surface E-field of Wearable and Reconfigurable Microstrip Patch Antenna at (a) 2.44 GHz (b) 3.54 Ghz

The patch antenna, employed on wearable material like denim jeans, gives the directivity values of 8.66 and 9.41 dBi at the resonant frequencies of 2.44 and 3.54 GHz. Fig. 6 a and b shows the 3D far-field radiation plots at 2.44 and 3.54 GHz bands which reports that the antenna has directional far-field pattern.



(a)



(b)

Fig. 6. 3D Directivity of Wearable and Reconfigurable Microstrip Patch Antenna at (a) 2.44 GHz (b) 3.54 GHz

TABLE III
SUMMARIZED RESULTS

Parameters	Switch On	Switch OFF
Frequency	2.44 GHz	3.54 GHz
Directivity	8.66 dBi	9.41 dBi
Gain	5.73 dB	9.17 dB
VSWR	1.069	1.05
S_{11}	-29.5 dB	-32.2 dB
Efficiency	51 %	94.6 %
Impedance	51.5 Ω	52.4 Ω
Bandwidth	2 %	1.13 %

IV. CONCLUSIONS

In this paper, the design of wearable dual band frequency reconfigurable microstrip patch antenna has been presented. The proposed antenna can be used for body- worn and wearable applications at Wi-Fi (2.44 GHz) and WiMAX (3.54 GHz) frequency bands. This wearable has the key advantage that it can be reconfigured for operation at two different frequency bands depending upon the need and switching mode. The efficiency values achieved by the microstrip patch have been observed to be 51 and 94.6% at 2.44 and 3.54 GHz frequencies. It has been reported that the antenna provides -10dB band-widths of 2% (500 MHz) and 1.13% (40 MHz) at 2.44 and 3.54 GHz bands, respectively. The proposed wearable microstrip patch antenna has a directional 3D far-field radiation pattern with matched input impedance and has achieved the E/H-plane gain values of 5.73 dB at 2.44 GHz and 9.17dB at 3.54 GHz. The proposed wearable frequency reconfigurable dual band microstrip patch antenna has the attractive potentials to be used in wearable, medical, safety, rescue, body-worn, security and military applications.

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